Fluxes of soil carbon dioxide, nitrous oxide and firedamp in broad-leaved/Korean pine forest

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Abstract: To understand influence of litters on the emission/absorption of CO_2, N_2O and CH_4 in broadleaved /Korean pine forest in Changbai Mountain, fluxes of soil CO_2, N_2O and CH_4 were measured by closed static chamber technique, from Sept 3, 2002 to Oct 30, 2003 in two types of soil ecosystems, of which one was covered with litters on the surface soil, and the other had no litters. The results showed that litters had significant influences on CO_2, N_2O and CH_4 fluxes ($p<0.05$). Their diurnal change patterns of plot with litters and litter-free plot were similar, and they all showed emission/absorption peak at 18:00. The diurnal fluxes of CO_2 and N_2O of plot with litters were significantly higher than those of the litter-free plot, while the diurnal flux of CH_4 of plot with litters was lower than that of litter-free plot. The fluxes of CO_2, N_2O, and CH_4 showed the similar seasonal patterns for both plots. The fluxes of CO_2, CH_4 showed their peak fluxes in June, but the fluxes of N_2O showed its peak emissions in August. The annual fluxes of CO_2 and N_2O of plot with litters were significantly higher than those of the litter-free plot, while the annual flux of CH_4 of plot with litters was lower than that of litter-free plot.

Keywords: Flux; CO_2, N_2O and CH_4; Seasonal variation; Diurnal variation

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Introduction

Since the 19th century, global surface temperature has increased by 0.2-0.6 (Houghton *et al.* 1996), and it is still increasing at a rate of 0.53 per century (Liu 1998). Observations and further analyses suggest that industrialization acceleration, forest denudation, unreasonable land use, rapid population growth and greenhouse gases emission by human activities have upset the natural source-sink balance of the greenhouse gases (Houghton *et al.* 1996; Wang 2000), which will lead to a continual change of the concentration of atmospheric greenhouse gases and the durative global warming (Lashof *et al.* 1990; Rodhe 1990). The characteristics of the main greenhouse gases and their contents in the atmosphere were listed in Table 1.

Forest ecosystem is an important part of terrestrial ecosystem. It plays a key role in gas cycle between the atmosphere and the earth's surface. Thus, more scientific understandings for these biogeochemical cycles in forest ecosystem are essential to describe past and current functions of forest ecosystem and to predict the response of forest ecosystem to global climate change. Therefore, it is of great importance to conduct long-term and continuous supervision on the greenhouse gases emissions in forest ecosystem.

The emission and absorption of greenhouse gases in forest soil mainly depended on natural biological course, including land use change, fertilization, forest harvest, etc.. The studies on soil greenhouse gases throughout the world started from 1980's. Up to date, chamber technique, tower technique and isotope technique have been ever used in measurement of greenhouse fluxes (Bouwnan 1990). But the chamber technique was primarily used on agriculture soil and tundra soil, and the reports on forest soil with high organic matter content were quite few. The increasing concentration of greenhouse gases in the atmosphere is threatening the sustainable development of the human society, so it is important to investigate greenhouse gases emission /absorption in forest soil.

Table 1. The characteristics of the main greenhouse gases and their contents in the atmosphere.

Gas	Atmospheric concentration $/\mu mol \cdot mol^{-1}$	Annual increase rate /%	Survival time /a	Greenhouse effect (CO_2=1)	Contribution rate /%
CO_2	355	0.5	50-200	1	55
CH_4	1.714	0.8	12-17	11	15
N_2O	0.31	0.25	120	270	6

In this study, emissions/absorption of CO_2, N_2O and CH_4 in forest soil were measured by closed static chamber technique from CERN (Chinese Ecosystem Research

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Network) in broad-leaved Korean pine forest in Changbai Mountain, north of China. This study will potentially contribute to predicting the future global climate change, understanding the roles of forest in global changes, and settling some environmental issues.

Study area and methods

Site description

The study was conducted in the northern slope of Changbai Mountain in Natural Reserve Zone (Erdaobaihe Town, Antu County; 128°28′E, 42°24′N), with an altitude of 736 m. Mean annual precipitation is 600-900 mm and the mean annual temperature ranges from -7.3°C to 4.9°C. The typical broad-leaved Korean pine forest was selected as the sampling site. Forest community is Broad-leaved/Korean pine forest dominated by *Pinus koraiensis*, *Acer mono*, *Tilia amurensis*, *Ulmus mongolica*, *Fraxinus mandshurica*, and *Quercus mongolica*. The average diameter at breast height of *Pinus koraiensis* is 28.9 cm, average tree height 25 m, canopy density 0.8, and the tree density is 560 per hectare. Shrubs include *Corylus mandshurica*, D*eutzia amurensis*, *Eleutherococcus senticosus*, *Corylus mandshurica etc.* The herbage includes *Carex sideroticta*, *Brachybotrys paridiformis*, *Urtica angustifolia*, *Impatiens molitangere* and some ferns (Li 1981). The soil is mountain dark-brown forest soil. The pH value is 5.4 in the surface layer soil (Cheng 1981).

Experimental design

Fluxes of CO_2, N_2O and CH_4 of soil were measured by closed static chamber technique during Sept. 3, 2002 to Oct. 30, 2003. The measurements were carried out once or twice a week, with a total of sixty-one times. Two sampling plots were selected. In one plot, litters were kept on the soil surface and the plants in bottom chamber were cut to the roots, while in the other plot, the litters were cleaned out to expose the surface soil and the plants were also cut to the roots. For each plot, three repetitions were conducted. During measurement, the stainless steel chamber, which was 0.5 m×0.5 m in basal area and 0.5 m in height, was inserted into the soil to the bottom of closed flume. Soil temperatures and moistures of different profiles (0 and 5 cm) were measured. At the same time, the environmental factors such as CO_2 concentration, temperature and pressure of atmosphere were recorded. Gas sample was taken with 100 ml syringes equipped with a three-way stopcock every 10 min, and the first 20 ml gas were abandoned, because it might contain the gas taken at the latest sample gas. Then, the gas samples were sealed and brought back to the lab. The experimental methods were described in detail by Wang (2000).

Gas analysis

The gas concentration was analyzed by using HP 5890 II gas chromatography, which was equipped with a flame-ionization detector (FID) and an electron capture detector (ECD). As FID only has strong signals to organic matters and it does not respond to inorganic matters, FID was used as CO_2 detector. Before CO_2 gas entered FID, it was transformed into CH_4 via (Ni) H_2 and could be detected. High pure nitrogen (99.999%) was used as the carrier gas. Hydrogen (99.999%) was used as fuel, the carrier gas flow rates were 25 $ml\cdot min^{-1}$, 40 $ml\cdot min^{-1}$, 450 $ml\cdot min^{-1}$, respectively.

Data analysis

The gas flux was expressed by the corresponding gas flows over the sampling period and the calculation equation was as follows:

$$F=\rho\frac{V}{A}\frac{P}{P_0}\frac{T_0}{T}\frac{dC_t}{dt}=\rho\cdot h\cdot\frac{dC_t}{dt}$$

where F is soil CO_2 flux (mg $CO_2\cdot m^{-2}\cdot h^{-1}$), ρ is gas density at the test temperature. h, A, V are the height, the bottom area, and the volume of chamber, respectively. C_t is the concentration of mixed volume ratio of gases inside chamber at t time. T_0 and P_0 are absolute temperature and gas pressure under standard condition, respectively. P is gas pressure in the sample plot, and T is absolute temperature while sampling. Thus, if F is the positive value, it means the gas emission from the soil into the atmosphere, and if F is negative value, then it represents a contrary flux direction or soil absorbing this gas from the atmosphere.

Results and analysis

Diurnal variations of CO_2, N_2O and CH_4 fluxes

The diurnal fluxes of soil CO_2, N_2O and CH_4 as well as soil temperature and moisture were measured at the same time. The diurnal temperature and moisture at surface soil and at a depth of 5 cm for the day of measuring gas fluxes were shown in Fig. 1A, B. The two figures showed that soil temperature and soil moisture at a depth of 5 cm were both the highest at 18:00. hour. The diurnal variation of soil CO_2 emission flux (Fig. 2A) and soil temperature on surface layer were identical. The peaks of soil CO_2 flux both for plot with litters and litter-free plot occurred at the highest temperature of soil at 18:00 hour and the minima of soil CO_2 flux for the plot with litters and litter-free plot were at 3:00 and 6:00 hour respectively (Fig. 2A). The diurnal variation range of soil CO_2 flux was from 317.63 to 852.24 mg $CO_2\cdot m^{-2}\cdot h^{-1}$ in the plot with litters, and between 233.78 and 367.22 mg $CO_2\cdot m^{-2}\cdot h^{-1}$ in the litter-free plot. The optimal temperature for soil CO_2 emission ranged from 17℃ to 24℃ (Robert *et al.* 1985), but the sensitivities of temperature change for CO_2 emission fluxes in the two plots were different due to the fact that the decomposition activities of litters mostly depended upon soil surface temperature rather than upon that at a depth of 5 cm.

The diurnal variation patterns of soil N_2O emissions in the two treatments were similar, and the maxima both occurred

at 18:00 hour and the minima appeared at 12:00 and 14:00 hour, respectively (Fig. 2B). According to Huang (1995), light intensity had a significant correlation with N_2O emission at a certain temperature. The stronger light intensity was, the less N_2O emitted, and vice versa. Thus, the minimum of N_2O emission occurred at the noon. Soil microbes must use organic matters in litters or soil to fuel their activities (Wang 2003). Surface soil temperature at 18:00 hour was the highest at the measuring day (Fig. 1). This was beneficial to decomposition of litters, moreover metabolism and activities of soil microbes strengthened, which resulted in the higher emission of N_2O.

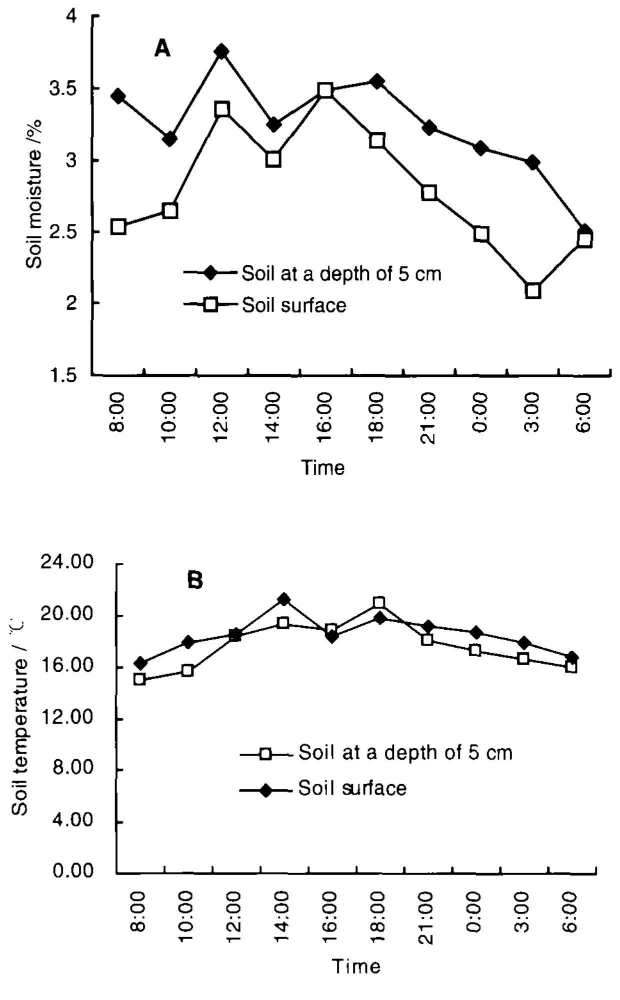

Fig.1 Diurnal moisture (A) and temperature (B) at soil surface and a depth of 5 cm

As the results shown in Fig 2C, forest soil was a pool of CH_4. Regardless of litters, the diurnal variation patterns of soil CH_4 absorption in the two plots were similar. They both had two absorption peaks at 14:00 and 18:00, respectively, and they both showed decline trends after 18:00, and reached the lowest absorption at 6:00 next morning. Some researchers thought that CH_4 oxidation could increased obviously with increase of soil temperature (Priemer *et al.* 1997), but others suggested that although temperature had a big influence on CH_4 oxidation, it was less important than water moisture (Klemedtsson *et al.*1997). According to meteorological records of Changbai mountain station, the diurnal soil moisture changed quite slightly (Fig. 1). Consequently, the effect of soil temperature on the diurnal CH_4 absorption was bigger than that of soil moisture in Changbai Mountain. Moreover the CH_4 absorption pattern was similar to the change pattern of soil temperature, which further validated this research result.

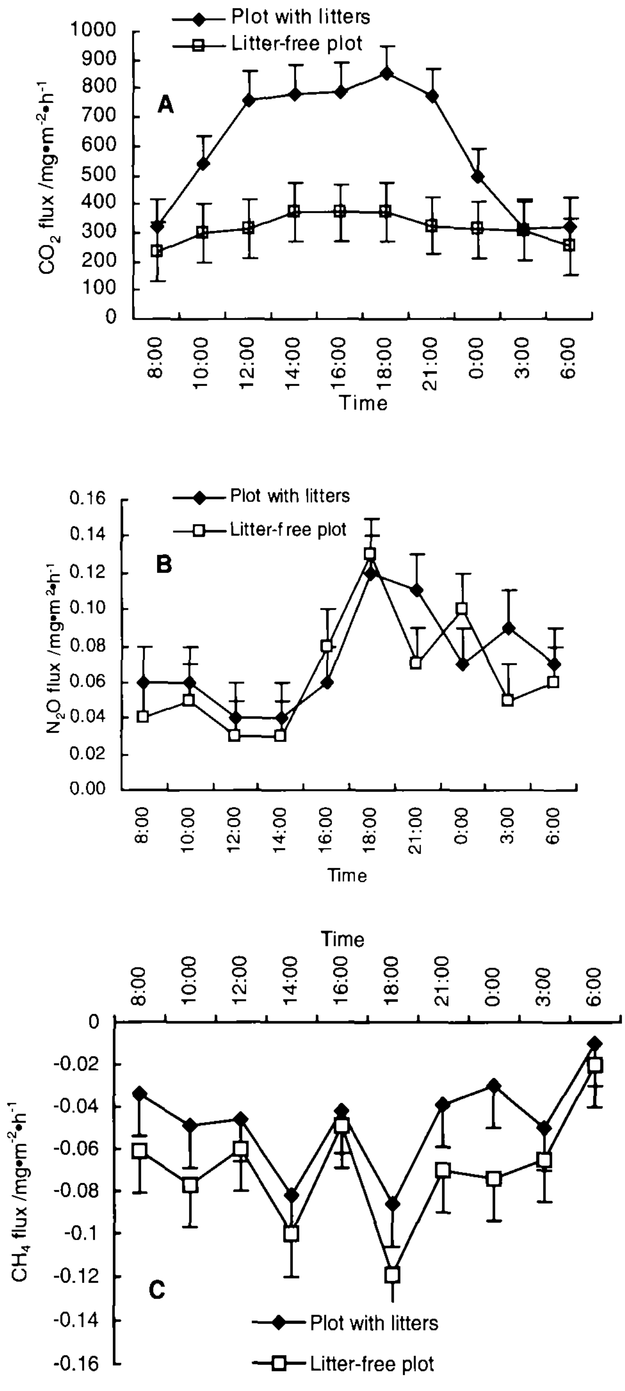

Fig.2 Diurnal CO_2, N_2O and CH_4 fluxes in the plot with litters and litter-free plot

A-- CO_2 flux; B-- N_2O flux; CH_4 flux

The litters had significant influences on the daily fluxes of CO_2, N_2O and CH_4 (Table 2). The emissions of CO_2 and N_2O in the plot with litters were significantly ($P<0.05$) higher than those in the litter-free plot, while the absorption of CH_4 in the plot with litters was significantly lower than that in the litter-free plot. This implied that litters on the forest soil would increase the emissions of CO_2 and N_2O, and decrease the absorption of CH_4.

Table 2. The daily average CO_2, N_2O and CH_4 fluxes in the two plots

	Average gas fluxes /mg· m^{-2}· h^{-1}		
	CO_2	N_2O	CH_4
Plot with litters	387.55a	0.05a	-0.05a
Litter-free plot	315.86b	0.03b	-0.07b

Note: The different letters showed there were significant differences at 5% level based on *t* test.

The seasonal fluxes patterns of CO_2, N_2O and CH_4

The monthly changes of temperature and moisture at surface soil and 5-cm deep soil for the time of measuring gas fluxes were shown in Fig. 3A, B. The figures showed that soil temperature at surface and a depth of 5 cm were both the highest in August, and the lowest in January.

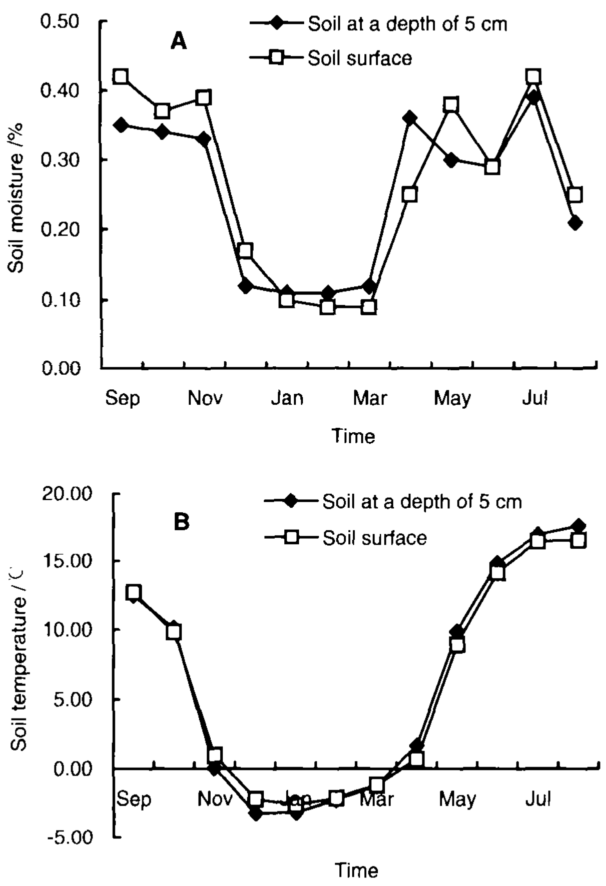

Fig. 3 Seasonal moisture (A) and temperature (B) at soil surface and a depth of 5 cm

CO_2 emissions of soil in broad-leaved/Korean pine forest changed significantly with season alternation (Fig. 4A). The CO_2 emission patterns of the two plots were both single peak curves. During the whole year, CO_2 emission were the lowest in February and went up linearly from the end of February to the end of June, then started to go down till October. These emission patterns of CO_2 might be regulated by temperature because they were consistent with change pattern of soil temperature in the year. In winter, early spring, and late autumn, the microbes were in a dormancy state due to low soil temperature, as a ruslt, the CO_2 emission of soil was very low. However, in late spring and summer, with the soil temperature rising, the soil microbes began activity, thus CO_2 emissions of soil rapidly increased.

There was a sudden decline of the CO_2 emissions of soil in July in the litter-free plot, while this phenomenon did not occurred in the plot with litters. This might be due to the fact that the soil moisture also influenced the CO_2 emission pattern. In July of 2003, the precipitation was very high, resulting in a high content of soil moisture (Fig. 3). This led to a bad permeability of soil, thus decreasing the CO_2 emission of soil.

The N_2O emission of soil in the two treatments showed the similar seasonal patterns (Fig. 4B). The peaks of N_2O emission both occurred in August. This might be due to the fact that the soil reached its optimal water capacity for the survival of soil microbes. Although the precipitation was low in spring, there still was a small N_2O emission peak. The possible reason for this was that N_2O emitted in winter was enclosed in the soil when the soil was frozen, but in late spring, the N_2O was released again when the soil was melted (Du *et al* 2001), thus,in spring the N_2O emission flux had a little increase. It was reported that during the soil thawing, N_2O flux of soil could reach the highest in the whole measuring year (Goodroad *et al.* 1984). It was suggested that decomposition of litters was correlated with some ecological factors, such as temperature, moisture and pH (Daubenmire *et al.* 1963; Wakesman *et al.* 1931; Hill 1983) besides their chemical components (Guo 1994). From September, the precipitation began to decrease and soil temperature also largely declined. These all held back litters decomposition, thus decreaing N_2O emission of soil. In autumn, N_2O emissions of soil were very low. In winter, soil microbes were almost in dormancy state, so the N_2O emissions were also very low.

In our study, we found that CH_4 absorption in the two treatments showed the similar seasonal variation patterns as the highest absorptions occurred in summer and autumn (Fig. 4C). The CH_4 absorption curves showed two peaks, one in June, and the other in September. In Changbai mountain area, precipitation was mostly in summer, accounting for more than 60% of the annual precipitation. The high soil moisture caused low permeability of soil, which was not good for CH_4 oxidation. Nebsit and Breitenbeck (1992) had suggested that the optimal temperature range

for CH_4 oxidation was 20-30℃. In summer, soil temperature was close to the optimal temperature. Probably, the positive influences of temperature exceeded the negative influences of low soil permeability. Therefore, the CH_4 absorption flux in summer was the highest. In spring and winter, soil temperature and moisture were both unfavorable for CH_4 oxidation. Therefore, CH_4 absorptions were very low.

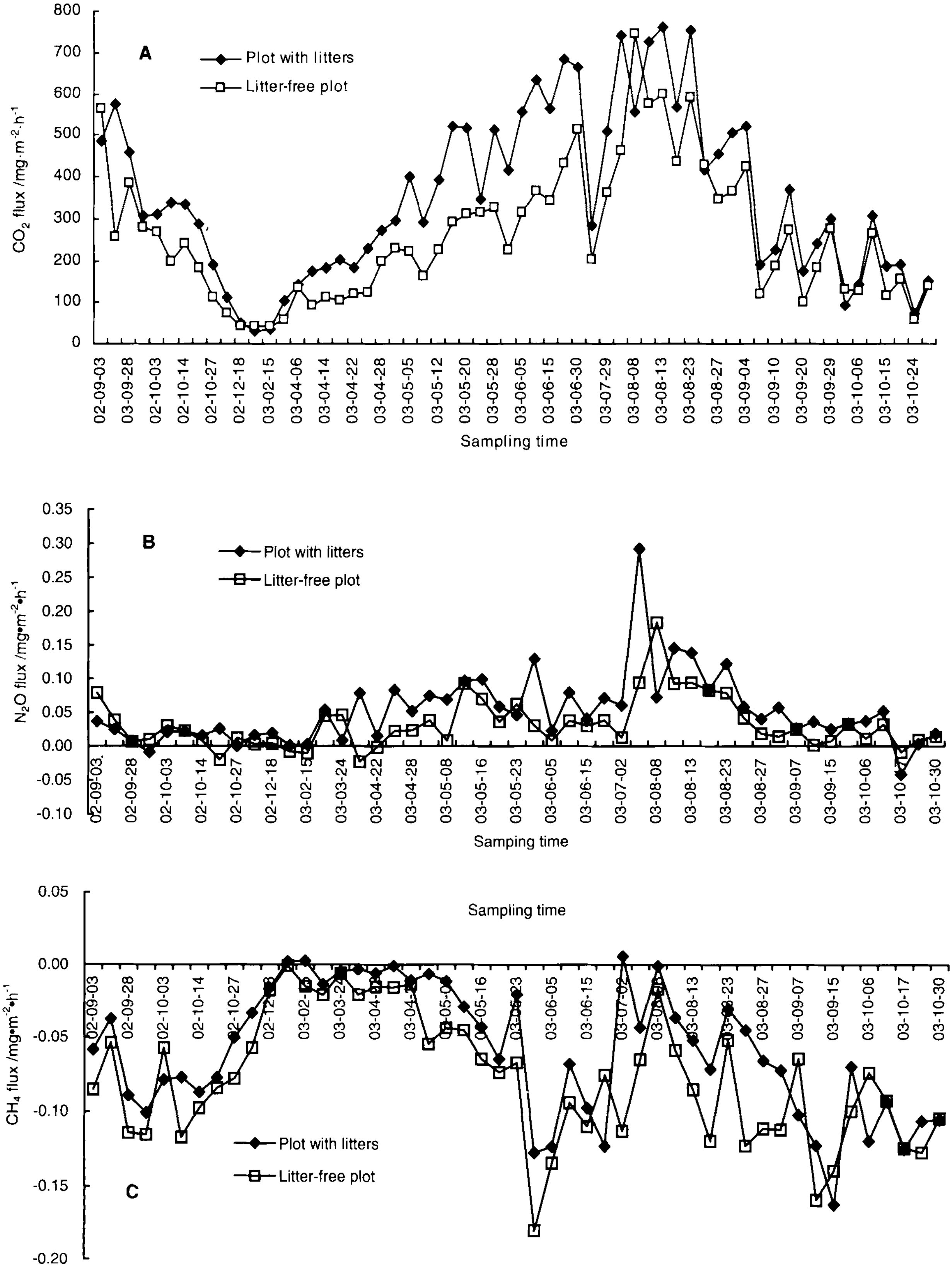

Fig. 4 Seasonal CO_2 (A), N_2O (B) and CH_4 (C) fluxes in the plot with litters and litter-free plot

The litters also had significant influences on the annual average fluxes of CO_2, N_2O and CH_4 of soil (Table 3). The emissions of CO_2 and N_2O in the plot with litters were significantly ($P<0.01$) higher than those in the litter-free plot, while the absorption of CH_4 in the plot with litters was significantly lower than that in the litter-free plot. This implied that litters on the forest soil would increase the annual emissions of CO_2 and N_2O, but cut down the absorption of CH_4, which was consistent with the influences of litters on daily average fluxes of CO_2, N_2O and CH_4 of soil.

Table 3. The annual average fluxes of CO_2, N_2O and CH_4 in the two kinds of plots

	Average gas fluxes /mg· m^{-2}· h^{-1}		
	CO_2	N_2O	CH_4
Plot with litters	444.56a	0.044a	-0.039a
Litter-free plot	242.36b	0.023b	-0.058b

Note: The different letters showed there were significant differences at 5% level based on *t* test.

Conclusion

Although litters had significant influences on CO_2, N_2O and CH_4 fluxes of soil, their diurnal and seasonal change patterns of plot with litters and litter-free plot were similar.

The emissions of CO_2 and N_2O and the absorption of CH_4 of soil had the similar diurnal patterns for both plots. They all showed emission/absorption peak at 18:00. And the litters had significant influences on the diurnal fluxes of CO_2, N_2O and CH_4 of soil, the daily fluxes of CO_2, N_2O in plot with litters were significantly higher than those of the litter-free plot, while the daily flux of CH_4 in plot with litters was lower than that of litter-free plot.

The fluxes of CO_2 N_2O, and CH_4 of soil had the similar seasonal patterns for both plots. CO_2, CH4 of soil showed their highest fluxes in June, while N_2O of soil showed its highest emissions in August. The litters also showed significant influences on the seasonal patterns of CO_2, N_2O and CH_4 fluxes. The annual fluxes of CO_2 and N_2O of plot with litters were significantly higher than those of the litter-free plot, while the annual flux of CH_4 of plot with litters was lower than that of litter-free plot.

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